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Tomato Leaf-Mold
The Use of Fungicides for Its Control in Greenhouses

By E. F. Guba

The culture of greenhouse tomatoes is an important industry in Massachusetts, and the area devoted to this crop has increased considerably in recent years. Leaf-mold is the most serious disease affecting the crop. The loss of one to two months of pickings of the fall crop and one month of the spring crop as the result of this disease is common. Past recommendations regarding the proper choice of fungicides for its control are conflicting and not based on experimental evidence, and growers who have used fungicides have not obtained control. This investigation has considered the merits of different types of fungicides. An effective material, and a practical method of application, have been discovered which are recorded in this bulletin.

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AGRICULTURAL EXPERIMENT STATION,
AMHERST, MASS.

TOMATO LEAF-MOLD

THE USE OF FUNGICIDES FOR ITS CONTROL IN GREENHOUSES [1, 2]

By E. F. Guba, Assistant Research Professor of Botany

INTRODUCTION

Tomato leaf-mold caused by the fungus *Cladosporium fulvum* Cke. is the most serious disease of greenhouse tomatoes in Massachusetts. Relatively little experimental work has been done to determine the effect of fungicides on the disease, yet there is recommended in the literature a variety of materials the efficacy of which is unsupported by published evidence. Commercial growers have tried most of the materials suggested without success. Experimental work with fungicides in greenhouses has not received much recognition largely because successful control of this disease has been considered a matter of proper management of ventilation and heating. In establishments where management might successfully be practiced it usually fails.

REVIEW OF LITERATURE

An effective fungicide for this fungus has been a much discussed subject among pathologists. The earlier literature on the subject has been reviewed by Makemson (22). Previous to his study of the fungus some authorities recommended copper mixtures and others sulfur, while others were unable to obtain results with either group of fungicides. Makemson found from spore toxicity tests that Bordeaux mixtures, ammoniacal copper carbonate and potassium sulfide were entirely ineffective and that formaldehyde at the rate of 1 ounce of a 40 per cent solution to 2½ gallons of water (.12 per cent) and self-boiled liquid lime-sulfur were toxic while commercial liquid lime-sulfur 2.5 per cent showed promise. His control work on tomato plants substantiated the results of his spore toxicity tests with Bordeaux mixtures, likewise showed lack of value of sulfur dust and formaldehyde and the slight superiority of commercial and self-boiled lime-sulfur. Makemson's work left the impression that Cladosporium is not as susceptible to copper as to sulfur. This is unfortunate, for his results from self-boiled and concentrated lime-sulfur solutions were too meagre and conflicting to afford an accurate estimate of their value, and dusting sulfur proved of no value at all. Williams (38) reported that sulfur suspensions, colloidal sulfur, sodium polysulfide 2.5 per cent, potassium sulfide .5 per cent, ammonium polysulfide .5 per cent, Cheshunt Compound .5 to 2 per cent, copper silico-fluoride .2 to .5 per cent, nickel silico-fluoride .5 per cent, and barium silico-fluoride (sat. sol.) prevented germination while sodium polysulfide .5 to 1 per cent and lime-sulfur .5 to 2 per cent permitted germination. Of the materials which prevented germination, only potassium sulfide, ammonium polysulfide and Cheshunt Compound .5 to 1 per cent proved safe to tomato foliage, but when applied to infected leaves none affected the viability of the spores. Neither Makem-

[1] The writer is indebted to Professor A. Vincent Osmun, Head of the Department of Botany for valuable suggestions and criticisms in the preparation of the manuscript of this Bulletin.

[2] The information in this bulletin is based on the results of experiments conducted by the writer at the Market Garden Field Station, Waltham, and in commercial greenhouses in eastern Massachusetts.

son nor Williams stated the temperatures under which the tests were conducted and both failed to consider the possible relation of temperature to the activity of sulfur compounds. Parker (27) reported good results with ammoniacal copper carbonate wash. Alvesco mildew powder, a copper and sulfur dust of English manufacture, was recommended by A. M. D. (7), Parker (27) and Dyke (8).

Hasper (12) compared sulfur, copper salts and Uspulun and reported best results with .5 per cent Uspulun applied at 8 to 10 day intervals. In an anonymous paper (1) from Holland, Uspulun .5 per cent and Solbar 1 per cent were reported to give effective control. Solbar caused foliage burning but Uspulun none. Triebels (33) advised treatments with .5 per cent Uspulun beginning with the first appearance of leaf-mold and repeating at 2 to 3 week intervals up to the time the fruit becomes large. Since the fruits acquire the taste of phenol at this period, he advised using 1 per cent Solbar for subsequent treatments. Hofferichter (13) obtained good control with 1 per cent Solbar. Baehr (2) compared Bordeaux, Cosan and Solbar and reported that Solbar alone gave excellent control, while the other materials were of no account. Jonassen (18) advised spraying every fourteen days with 1 to 1.5 per cent Germinal or Uspulun beginning when the houses are set, and with a 5 per cent solution if the disease is already present.

Sulfuring of the heating pipes has been recommended for combating Cladosporium by Massey and Rhodes (23) and Parker (27). Manufactured devices for vaporizing sulfur, such as Campbell's Patent Sulfur Vaporizer and the Rota-Generator, have been recommended for controlling Cladosporium by Bewley (6) and A. M. D. (7), but Baehr (2) reported no control with the Rota-Generator.

As the literature reveals, many materials have been suggested. The recommendations concerning the choice are contradictory and inconsistent, and those materials which have been reported of merit are unsupported by adequate evidence. It has seemed desirable, therefore, to determine the merits of different fungicides in the control of this disease.

LABORATORY CONTROL WITH FUNGICIDES

Effect of Fungicides on Spore Germination

The technique employed by Makemson (22) and Williams (38) for determining the effect of fungicides on the germination of Cladosporium spores is contrary to natural methods of dissemination of the fungus and inoculation of the plants in the greenhouse. Makemson applied spores in water drop suspensions to glass surfaces bearing dry deposits of the fungicide, and spores in drops of the fungicide on clean cover glasses. The results by both methods of study were identical. Williams applied water suspensions of spores to glass surfaces bearing dry deposits of the fungicide.

Cladosporium spores are capable of germinating in moisture saturated air and in the absence of the water drop. Spores are dispersed in the greenhouse through the medium of the air and in the dry state, being liberated by disturbing leaves affected with mold. The common practice of tapping the plants with sticks to assist pollination of the flowers is a means of producing spread and epidemics of disease. Under the usual conditions of growing greenhouse tomatoes water is not a carrier of the inoculum. In determining the merits of fungicides for preventing infection, obviously the logical technique to follow is that of applying dry spores to dry fungicidal deposits and of exposing dry spores to contact with dusts or liquids, drying, and then

exposing the slides to optimum conditions for spore germination. For tests here reported various methods of technique were considered with the view of determining under what conditions control could be expected. The tests were conducted at different degrees of temperature. An outline of the methods of technique used follows:

Method I. Dry spores were applied with a camel's hair brush to glass slides bearing a dry covering of fungicide. This method of technique simulates most closely the conditions obtained on sprayed foliage and offers the most satisfactory means of determining the efficacy of the dry chemical residue in protecting the foliage from infection.

Method II. Dry spores were applied to clean glass slides which were subsequently dusted or sprayed. The spray was permitted to dry previous to incubation.

Method III. Technique was similar to II except that slides were incubated wet. By methods II and III the efficacy of the sprays as disinfectants was demonstrated, and by II the merits of the dust in preventing germination.

Method IV. Water drop suspensions of spores were placed on slides covered with the dry fungicide. Where fungicidal activity occurs under the conditions surrounding this method of technique it may be inferred that affirmative results can be expected on wet foliage in the greenhouse.

Method V. Glass slides brushed with dry spores were inverted and rested at a distance of 3 mm. above the dry fungicide. This method served to demonstrate the merits of the fungicide as a fumigant.

Spraying and Dusting Materials.

Study of Table 1 reveals significant data bearing upon the control of the disease with fungicides, not considered in previous investigations. As the data show, dusting sulfurs are of no value in preventing germination by any of the methods of testing and under the range of temperatures considered. The data supports Makemson (22) who showed that sulfur dust is of no value, but are contrary to the results of Williams (38) which show that sulfur suspensions and colloidal sulfur are toxic. Barker, Gimingham and Wiltshire (4) reported that Cladosporium is not nearly as sensitive to sulfur as other fungi. These studies show that sulfur dusting materials are not effective and cannot be expected to offer control of the disease.

Some toxicity was manifested by Hammond's Grape Dust against spores conveyed in the water drop. This was due to its copper content. The composition of Grape Dust is sulfur 64 per cent, copper sulfate 2.5 per cent, and inert material not more than 33.5 per cent.

Hammond's Slug Shot did not control germination in contact with dry spores but in water drops abnormal germ tubes resulted. Hammond's Slug Shot contains gypsum and free sulfur, calcium hydroxide, silica, iron and aluminum oxides, arsenic, less than 1 per cent of metallic copper, less than 2 per cent of organic material and traces of nicotine and carbolic acid.

Schloesing's sulfur, a dusting mixture recovered in the manufacture of artificial gas, also failed under every method of technique. It is a finely divided product and easily wet with water. According to analyses there is present 36.42 per cent total sulfur in the original and 25.44 per cent sulfur in carbon bi-sulfide extract. The ash is highly colored with iron oxide (Fe_2O_3). The material also contains phenols and cyanides.

Herbert and Herbert colloidal sulfur failed by every method of study used to control germination. The concentrated product is strongly acid. A 5 per cent mixture is not toxic.

Table 1. Toxicity of Fungicides to Germinating Spores.

Fungicide	I Dry spores applied to dry residue			II Dry spores treated with fungicide; incubated dry			III Same as II but incubated wet			IV Water suspension of spores applied to dry residue		V Dry spores exposed to fungicide at a distance	
	70°	80°	90°	70°	80°	90°	70°	80°	90°	70°	80°	70°	90°
Anchor Brand Sulfur Dust				+	+	+				+	+	+	+
Niagara Kolo Dust.......				+	+	+				+	+	+	+
Ortho Sulfur Dust........				+	+	+				+	+	+	+
Trick Sulfur.............				+	+	+				+	+	+	+
Hammond's Grape Dust..				+	+	+				+*	+*	+	+
Hammond's Slug Shot....				+	+	+				+*	+*	+	+
Schloesing's Sulfur........				+	+	+				+	+	+	+
H. & H. Colloidal Sulfur 5%	+	+	+	+	+	+				+	+	+	+
Lime-Sulfur 10%.........	+	+	+	+*	+*	+*	+*	+*	+*	+	—	+	+
Lime-Sulfur 1%..........	+	+	+	+	+	+	+	+	+	+	+	+	+
Potassium Sulfide .08%...	+	+	—	+	+	—	+	+	—	+	+	+	+
Potassium Sulfide .4%....	+	—	—	+*	—	—	+*	—	—	—	—	+	+
Solbar 1%...............	+	+	+	+	+*	+*	+*	+*	+*	+	+	+	+
Sulfuric Acid .05%.......	—	—	—	—	—	—	—	—	—	—	—	+	+
Sulfuric Acid .025%......	—	—	—	—	—	—	—	—	—	+	+	+	+
Sulfuric Acid .02%.......	—	—	—	—	—	—	—	—	—	+	+	+	+
Naphthalene Dust........				—	—	—				—	—	—	—
Naphthalene-Lime Dust 1-2				—	—	—				—	—	—	—
Schacht's Naphtal-Schwefel				—	—	—				—	—	+	+
Copper-Lime Dust 10-90..				+	+	+				—	—	+	+
Copper-Lime Dust 14-86..				+	+	+				—	—	+	+
Copper-Lime Dust 19-81..				+	+	+				—	—	+	+
Niagara D-25 Copper Dust				+	+	+				—	—	+	+
Bordeaux 1-1-50..........	+	+	+	+*	+*	+*	—	—	—	—	—	+	+
Bordeaux 6-6-50..........	+	+	+	+*	+*	+*	—	—	—	—	—	+	+
Copper Sulfate .05%......	+*	+*	+*	—	—	—	—	—	—	—	—	+	+
Copper Sulfate .04%......	+*	+*	+*	—	—	—	—	—	—	—	—	+	+
Copper Sulfate .03%......	+	+	+	+*	+*	+*	+*	+*	+*	+	+	+	+
Lime Dust...............				+	+	+				+	+	+	+
Semesan .2%............	—	—	—	—	—	—	—	—	—	—	—	+	+
Uspulun .2%............	—	—	—	—	—	—	—	—	—	—	—	+	+
Formaldehyde .4%.......	+	+	+	—	—	—	—	—	—	+	+	—	—
Formaldehyde .1%.......	+	+	+	—	—	—	—	—	—	+	+	+	+
Formaldehyde .04%......	+	+	+	+	+	+	+	+	+	+	+	+	+
Burning Sulfur...........	—	—	—	—	—	—				—	—	—	—

+ germination; fungicide not effective.
— no germination; fungicide effective.
* germination considerably suppressed but fungicide not considered effective.

A 1 per cent solution of lime-sulfur was not effective. A 10 per cent solution showed merit by methods of study II and III. In the water drop (IV) at the higher temperatures germination was inhibited.

Potassium sulfide in a .08 per cent solution was toxic at 90° F. (I, II, III), but spores sown in a water drop were not affected at 70° and 80° F. A .4 per cent solution gave disinfection (II and III) at 80° and 90° F. Germination was controlled in the water drop (IV) and the dry residue (I) was toxic at 80° and 90° F.

Solbar is a sulfur powder. It contains about 35 per cent water soluble sulfur and the water solution contains chiefly barium tri-sulfide. The material was ineffective by methods of study I and IV but gave some control of

germination when spores were wetted by the spray (II and III), especially at the higher temperatures. The data do not suggest that control of the disease can be expected from its use, although Hofferichter (13), Anon. (1), Baehr (2) and Triebels (33) have regarded the product as having merit.

Sulfuric acid of the specific gravity 1.835-1.840 in a .02 per cent solution was toxic to spores wetted by the spray and its residue was likewise toxic to dry spores (I). A .01 per cent solution was weakly fungicidal but its residue was inactive. A residue of a .05 per cent solution was lethal to spores applied in the water drop, but residues of weaker solutions were not effective.

Naphthalene flakes were placed in moist Petri dishes in which dry spores on slides were incubated for germination. The vapors emanating from the deposits were lethal. Naphthalene dust prepared by grinding naphthalene flakes was toxic in water and similar control was obtained with a naphthalene-lime dust containing 1 part of naphthalene and 2 parts of lime.

Schacht's Naphtal-Schwefel is the only dusting material encountered that proved effective by the two methods of study (II, IV). It appeared from these tests to be the most promising dusting material for combating leaf-mold. The product is manufactured in Germany and is recommended for surface mildews. It is a flesh colored powder, lacks the characteristic naphthalene odor and is not wettable with water. On warming or in water with sodium peroxide the naphthalene odor is noticeable. The material contains sulfur soluble in CS_2, sulfur by oxidation with Na_2O_2, combined naphthalene, CaO probably combined as hydrate and carbonate, and SiO_2, Fe_2O_3 and Al_2O_3. The naphthalene compound was not identified.

Dry spores dusted with copper powders (II) germinated normally, but when spores were applied in water drops to the copper deposit, germination was completely suppressed.

Bordeaux mixtures proved toxic when dry spores were wetted (III) and incubated immediately, but spores which escaped wetting were not affected. When the spray was allowed to dry previous to incubation (II) germination was not measurably affected. The germ tubes were observed to grow into the surrounding dry Bordeaux residue unaffected.

Copper sulfate in dilute solutions was toxic. Spores wetted with a .04 per cent solution of copper sulfate were killed and a dry residue of the same spray was lethal to spores applied in the water drop. Spores which escaped wetting (II and III) were not measurably affected. The dry residue of a .04 per cent solution exhibited toxicity to dry spores (I) but weaker dilutions did not.

Copper fungicides possess no merit in the absence of moisture. Williams (38) reported that copper salts are toxic in water and Makemson (22) claimed that Bordeaux mixtures and ammoniacal copper carbonate have little appreciable effect upon either germination or the growth of the germ tubes. In these studies, however, consistent control of germination in the water drop has been obtained. The results substantiate the effectiveness of copper materials on field tomatoes for combating Cladosporium reported by Edgerton and Moreland (10), Edgerton (9), Sherbakoff (30), and Weber and Ramsey (37). Moisture not only influences the growth of the fungus but also favors the activity of copper materials.

Lime dust was not toxic by either of the two methods of study (II and IV).

Organic mercury compounds were toxic to spores by methods of study I, II, III and IV. Uspulun was toxic at a .1 per cent strength. Semesan, at

a .1 per cent strength, was not toxic to spores applied in the water drop to the dry residue (IV), but was toxic by other methods of study. The effectiveness of the organic mercury compounds by all methods of study suggests the possibility of their use to control infection in the greenhouse.

Commercial 40 per cent formaldehyde at dilutions ranging from 1-100 to 1-400 (.4 to .1 per cent) was lethal (II, III). Dry spores on slides were placed in dishes moistened with formaldehyde (V) but only 1-100 and stronger mixtures produced a lethal atmosphere. Since the 1-100 mixture is fungicidal in the air as well as in the soil, its use for soil sterilization is preferable to a 1-400 mixture. Formaldehyde was ineffective by methods of study I and IV, and a strength of 1-1000 was ineffective by every method of study. The data suggest that disinfection of the greenhouse may be obtained by the usual method of drenching the soil with a 1-100 mixture and closing the greenhouse tight after the treatment.

The toxicity of the fumes of burning sulfur was very striking. Spores on slides confined within Petri dishes placed in a treated atmosphere were killed. The data indicate that the burning of sulfur between crops, as is generally practiced by growers, is an effective and desirable means of destroying hibernating parts of the fungus.

Other than naphthalene, formaldehyde and burning sulfur, none of the materials listed in Table 1 were of any fungicidal value as fumigants.

The residues of potassium sulfide, copper sulfate, sulfuric acid, and organic mercury sprays showed a toxic effect to spores applied dry to the slides (I). By this method of study some solution of the residue in moisture deposited on the surface of the slides occurred. This fungicidal effect was shown only by readily soluble materials such as noted.

Vaporized Sulfur.

On heating sulfur, amorphous particles of sulfur are discharged into the air, float about, and finally are deposited on exposed surfaces. These amorphous particles of sulfur are fluid and spread over the surface on which they fall. The sulfur droplets are very sticky. This is considered to be due to the fluid property of the sulfur which in this condition is able to rid the surface of air films. Barker and Wallace (5) report that sulfur distributed through the atmosphere by its vaporization not only furnishes a much more complete superficial covering than can be secured by dusting or spraying, but also possesses a remarkable power of adhesion, withstanding the action of heavy rains or sprays of water of considerable force. To compare the relative adhesiveness of vaporized sulfur and pure dusting sulfur, ten glass slides, each of an area of 3 square inches, were weighed with a chemical balance then exposed to an atmosphere treated with vaporized sulfur and again weighed. Similarly ten weighed slides were dusted with a pure dusting sulfur and reweighed. Both sets of slides were exposed to a rain of .36 inches then air dried in the laboratory and again weighed to determine the amount of loss from washing. (Experiment A.)

The experiment was repeated (Experiment B), but the amount of rain recorded was .04 inches. The relative adhesiveness of the two sulfurs is indicated quantitatively in Table 2. The data show that washing caused an appreciable loss of dusting sulfur but that its effect upon vaporized sulfur was negligible.

The dry particles of amorphous sulfur measure 1 to 5 microns in diameter. The largest, which are aggregates of smaller droplets, reach a diameter of 24 microns. The distance between the particles varies according to the density of

Table 2. Comparative Loss of Vaporized Sulfur and Dusting Sulfur after Exposure to Rain.

	Vaporized Sulfur		Dusting Sulfur	
	Experiment A	Experiment B	Experiment A	Experiment B
First weight of Sulfur, grams	.0528	.0591	.0620	.0464
Second weight of Sulfur, grams	.0510	.0579	.0054	.0252
Loss of Sulfur, grams	.0018	.0012	.0566	.0212
per cent	*3.4*	*2.0*	*91.3*	*45.7*

the deposit. Dense deposits show very little unoccupied space. Thin deposits show an extremely fine division of sulfur. In both cases distribution is extremely uniform (Plate I, C, D). The uniform distribution of vaporized sulfur on the plants and ground in the greenhouse is impressive. Such an intimate association between the fungus and sulfur is not obtainable with spraying or dusting materials (Plate I, A, B).

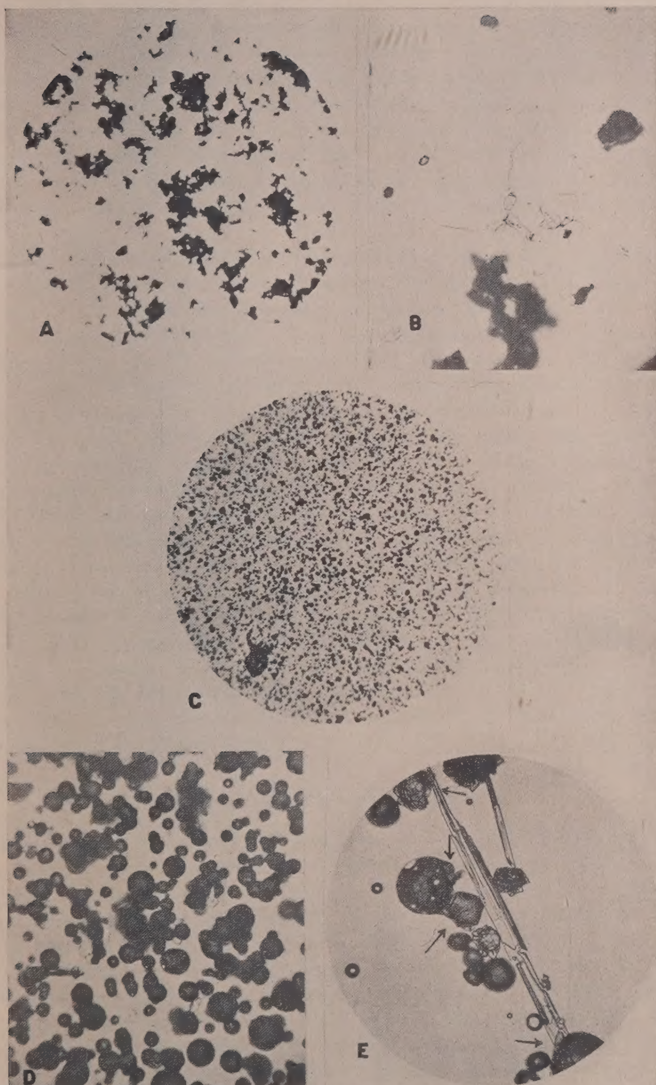
In a series of experiments, Cladosporium spores were exposed in different ways to sulfur vapors (Table 3) and then incubated for 48 hours in Petri dishes. The sulfur was evaporated slowly over an electric hot plate at moderate temperatures with free access to air. The spores were examined for germination at the termination of 48 hours and a final examination was made at the end of 72 hours. Duplicate slides were exposed, one group serving to determine the degree of acid present after exposure to sulfur vapors and the other after incubation. Constant chamber temperatures were maintained during the exposure of the spores to vaporized sulfur and during the period of incubation in Petri dishes. For these tests individual temperatures between 65° and 90° F. were used. Six tests of each method of technique were made.

Table 3. Effect of Vaporized Sulfur on Spore Germination.

Method of Technique		Average Percent Germination
I.	Dry Spores applied to vaporized sulfur residue	26.1
II.	Dry Spores exposed to vaporized sulfur	26.6
IV.	Spores in water drop applied to vaporized sulfur residue	15.9
V.	Spores in water drop exposed to vaporized sulfur	26 6
VI.	Spores sprayed with water, then exposed to vaporized sulfur	15.1
VII.	Spores sprayed with water after exposure to vaporized sulfur	1.6
Check.	Spores applied dry to clean glass slides	79.1
Check.	Spores applied in water drop to clean glass slides	55.8

This study failed to show that the toxicity of vaporized sulfur is due to its fumes. Varying degrees of control of germination were obtained by all methods of exposure, but instances of total inhibition were obtained only when spores were exposed in water to the vapors (V), or conveyed in water to the residue (IV), or atomized with water (VII) after exposure. It was anticipated that immersion in the sulfur droplets (II) would provide a greater lethal action than when the spores were applied to the dry residue

PLATE I



Microphotographs showing: Relative Physical Properties and Distribution of (A) Sulfur Dust, and (C) Vaporized Sulfur, x 75; (B) Germinating Cladosporium Spores Unaffected by Sulfur Dust, x 225; (D) Effect of Vaporized Sulfur in Preventing Germination of Spores, x 225; and (E) Cladosporium Spores Embedded in Dried Droplets of Vaporized Sulfur, x 300.

(I), but no such differences were consistently noted and the average of the results of the six tests by each of these two methods of exposure was the same. Sulfuric acid was produced only when moisture was present on the slides but in some instances no acid was produced in the presence of moisture, air conditions being practically the same. Acid media below a pH value of 5.7 were consistently toxic to spores, but the toxicity of vaporized sulfur was not due alone to acidity for in some instances complete control of germination occurred in alkaline and neutral media. The production of sulfuric acid did not appear to be influenced by either the exposure or the incubating temperatures, and toxicity was not correlated with any particular temperature.

Barker, Gimingham and Wiltshire (4) offered as one of the reasons for the toxic action of sulfur the irritant character of finely divided particles which stimulate to an injurious extent cells exposed to their action. One would expect a much greater irritant effect from vaporized sulfur in its change from the fluid to the dry state than from dry sulfur powders. The incrustations of sulfur surrounding the spores after drying of the droplets also would appear to interfere with the absorption of moisture necessary for germination (Plate I, E). Kraemer (19, 20) reported that when sulfur was heated very slowly with free access of air almost one-third of the vaporized sulfur was converted into sulfuric acid with very little or no sulfurous acid. On rapid heating and with very little air the proportion of sulfurous acid was increased while the amount of sulfuric acid formed was very much lessened. He asserted that the increased efficiency of vaporized sulfur over flowers or flour sulfur used as a dust is due to the increased proportion of sulfuric acid produced. Numerous workers have attributed the activity of sulfur to sulfuric acid and recognized that sulfuric acid is fungicidal in very weak dilutions, but Barker, Gimingham and Wiltshire (4) and Vogt (35) found that none of the compounds which might possibly be derived from sulfur, among which are mentioned sulfuric and sulfurous acids and sulfur dioxide, could account for its toxic action.

Control of Infection of Potted Plants

Those fungicides considered in the studies on spore toxicity were tested for their value in preventing infection of potted tomato plants. Two plants 8 to 12 inches high were used in each test. The potted plants were placed in a glass chamber 34x22x18 inches in size for the dust treatments. Small Feeney hand dusters were used for applying the dusting materials. The pots were placed in inverted and upright positions in the chamber to obtain coverings of dust on the lower and upper surfaces alike. The same chamber was charged with vaporized sulfur, and potted plants were confined in the charged atmosphere long enough to show a covering of sulfur. Sprays were applied with a quart capacity atomizer and both leaf surfaces were thoroughly wetted. The spray was permitted to dry before the plants were inoculated. The plants were inoculated in two ways: (1) sprayed with a water suspension of spores and (2) dusted with spores.

The water suspension of spores applied after the treatments was allowed to dry previous to incubation. The dry plants were placed in a glass chamber of 175 cu. ft. A saturated atmosphere was obtained and a range of temperatures from 80° to 95° F. prevailed. The fungus was incubated for 24 to 36 hours. The plants were then removed from the pots and planted in the greenhouse. When the disease was evident on the untreated controls, counts

of the leaflets were made to determine the relative merits of the fungicides considered. Only foliage present on the plants at the time of the treatments was considered in the counts.

When the fungus was applied in water (Table 4), the stronger Bordeaux mixtures furnished better control than the weaker, and the same was true of copper sulfate sprays. Copper-lime dusts proved efficient. Hammond's Slug Shot gave favorable control. Sulfur dusting materials were of no merit, but vaporized sulfur was effective. Lime-sulfur in 1-50 and 1-100 dilutions gave excellent control but also injury. Semesan .25 per cent was inferior to Uspulun .25 per cent. The difference is apparently due to the filler in Uspulun. When the plants were inoculated with dry spores (Table 4), only vaporized sulfur and Grape Dust gave significant control.

Table 4. Comparative Merits of Fungicides in Preventing Infection of Potted Tomato Plants.

Fungicide	Spores Applied in Water		Spores Applied Dry	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*
Check	100	57.0	183	85.2
Anchor Brand Sulfur Dust	108	32.4		
Grape Dust	100	19.0	99	6.0
Schloesing's Sulfur	119	46.2	141	55.3
Hammond's Slug Shot	90	10.0	131	62.5
Trick Sulfur	83	22.8	127	33.0
Vaporized Sulfur	93	4.3	123	7.3
H. & H. Colloidal Sulfur	95	22.1	144	38.1
Lime-Sulfur .2%	81	0.0		
Lime-Sulfur .8%			140	85.0
Lime-Sulfur 1.%	79	7.5		
Potassium Sulfide .08%			136	93.3
Schacht's Naphtal-Schwefel			154	39.6
Sulfur-Lime-Naphthalene 1-1-1	94	35.1	143	27.9
Sulfuric Acid .05%			135	87.4
Sulfuric Acid .04%			144	75.6
Copper Sulfate .06%	88	5.6		
Copper Sulfate .05%	88	17.0	150	77.3
Copper Sulfate .04%	98	47.9	149	62.4
Bordeaux 1-1-50	87	13.6	83	91.5
Bordeaux 4-4-50	95	5.2	117	57.2
Bordeaux 6-6-50	97	1.0		
Copper-Lime Dust 10-90	82	2.4	122	61.4
Copper-Lime Dust 20-80			124	40.3
Copper-Lime Dust 50-50	86	6.9		
Niagara D-25 Copper Dust			135	58.5
Semesan .25%	101	16.8		
Uspulun .25%	106	4.7		
Uspulun .1%			137	81.0

In a further experiment, plants were dusted in upright and inverted positions. When plants were inoculated with spores in water (Table 5) the best control was obtained with Grape Dust, copper-lime dust, vaporized sulfur, and Uspulun. When they were inoculated with dry spores (Table 5) significant control was obtained only with vaporized sulfur.

Table 5. Comparative Merits of Fungicides in Preventing Infection of Potted Tomato Plants. Both Leaf Surfaces Treated.

Fungicide	Spores Applied in Water		Spores Applied Dry	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*
Check	98	28.5	117	67.5
Grape Dust	117	5.1	90	23.3
Schloesing's Sulfur	123	26.8	82	17.0
Vaporized Sulfur	105	1.9	60	1.6
Solbar 1%	76	32.8		
Copper-Lime Dust 20-80	82	8.5	110	42.7
Uspulun .5%	88	2.2	123	58.5

In another test Bordeaux 4-4-50, Solbar 1 per cent and Uspulun .5 per cent offered a high degree of control when the treated plants were inoculated with spores in water (Table 6). When spores were applied dry, only Solbar offered effective control.

Table 6. Comparative Merits of Fungicides in Preventing Infection of Potted Tomato Plants.

Fungicide	Spores Applied in Water		Spores Applied Dry	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*
Check	122	55.7	211	85.3
Potassium Sulfide .4%	123	21.1	108	82.4
Solbar 1%	126	5.5	129	9.3
Copper Sulfate .05%			188	78.1
Bordeaux 4-4-50	129	0.7	146	19.8
Uspulun .5%	154	7.7	197	17.7

The materials which controlled infection on as much as 85 per cent of the foliage in these experiments are listed in Table 7. When water was used as a carrier for the inoculum, consistent favorable controls were obtained with Bordeaux, copper-lime dust, vaporized sulfur, and Uspulun; while copper sulfate, Slug Shot and lime-sulfur gave favorable control in the single test made. Solbar and Grape Dust were effective in one test and not in another, while Semesan permitted 16.8 per cent of the foliage to become infected against 4.7 per cent with Uspulun. All other fungicides tested were not effective. When spores were applied dry, only vaporized sulfur gave consistent control. Solbar gave favorable control in the single test in which it was tried, and Grape Dust was effective in one test and not in another. All other materials failed to offer satisfactory control. The poor control indicated by Semesan as compared with Uspulun and by Grape Dust (spores applied dry) were in reality significant controls although less than 85 per cent, the percentage on which Table 7 is based.

It is significant that when both leaf surfaces were covered with vaporized

Table 7. Summary of Control of Infection of Potted Tomato Plants with Fungicides.

	Spores Applied in Water			Spores Applied Dry		
	Times Tested	Times Control Favorable	Times Control Unfavorable	Times Tested	Times Control Favorable	Times Control Unfavorable
Grape Dust	2	1	1	2	1	1
Hammond's Slug Shot	1	1	0			
Vaporized Sulfur	2	2	0	2	2	0
Lime-Sulfur	1	1	0			
Solbar	2	1	1	1	1	0
Copper Sulfate	1	1	0			
Bordeaux mixture	2	2	0			
Copper-Lime Dust	2	2	0			
Semesan	1	0	1			
Uspulun	3	3	0	3	0	3

sulfur, superior and more uniform results were obtained than when the upper leaf surfaces only were protected. In general this was also true of other materials such as Uspulun, copper fungicides, etc., excepting sulfur, when plants were inoculated with a suspension of spores in water. This is explained at least in part by the fact that leaf infection is almost altogether hypophyllous. However, when plants treated in this manner were inoculated with dry spores, vaporized sulfur showed a marked effect, and Grape Dust a somewhat inferior effect.

The use of spraying and dusting materials in general is not applicable to greenhouse tomato culture, one reason being the undesirable effect of the fungicide upon the plant. Bordeaux mixture leaves a residue. Lime-sulfur is injurious and leaves a residue and sulfur odor. Uspulun is toxic to the foliage at .25 per cent strength, and both Semesan and Uspulun impart a phenol flavor to the tomato fruit. This fact has already been recognized by Triebels (33), Lüstner (21) and Jaenicke (17). Solbar leaves a heavy residue and sulfur-lime-naphthalene dust imparts a naphthalene flavor to the fruit. Vaporized sulfur and Grape Dust are desirable, but the results suggest that vaporized sulfur would offer the most satisfactory control under the conditions prevailing in tomato houses.

Data in Tables 1 and 7 show that materials toxic to the spores in laboratory tests gave the most satisfactory control of infection with few exceptions. Those showing this effect when the fungus was applied in water were copper materials, organic mercury compounds, vaporized sulfur, Slug Shot and Grape Dust. In the absence of water, vaporized sulfur gave the same effect, while Solbar, Uspulun, and Grape Dust did not. No control was anticipated with sulfur dusting materials, but potassium sulfide was expected to show some control of foliage infection and did not. Sulfuric acid proved of no value and Schacht's Naphtal-Schwefel, which was the most effective of all dusting materials considered, failed to give control in a single trial.

The remarkable control of foliage infection of potted plants with vaporized sulfur in contrast to the inconsistent control of spore germination in laboratory slide tests indicates that conditions existing on foliage are much more favorable for toxicity of vaporized sulfur than on slides in Petri dishes. Under greenhouse cultural conditions tomato foliage is usually bathed in thin

invisible films of transpired moisture, the amount of which is increased with high temperatures. Inferring from the results (Table 3, VI, VII) which are outstanding, this film of moisture provides suitable conditions for toxicity. The results show that protection from infection may be obtained by the presence on the leaves of a covering of vaporized sulfur, and that destruction of exposed sources of the fungus in greenhouses may be realized by vaporizing sulfur at frequent intervals.

COMMERCIAL CONTROL

Spraying and Dusting Materials

In the spring of 1925, at the Market Garden Field Station in Waltham, plats of tomatoes were treated with commercial liquid lime-sulfur 2 per cent, Bordeaux mixture 4-4-50, sulfur dust, copper sulfate-resin fish oil soap (½ pound of copper sulfate, 5 pounds of resin fish oil soap, 50 gallons of water), copper-lime dust 20-80, potassium sulfide and flour paste (5 pounds flour, 4 pounds potassium sulfide, 100 gallons water), ammoniacal copper carbonate of the usual formula, and New Jersey Dry Mix. The treatments were begun at the first appearance of the disease and continued at seven to ten-day intervals. No control was obtained. The disease was as prevalent in the treated plats as in the check. Lime-sulfur proved injurious to the foliage.

It might be assumed from the above that lack of control was due to the lateness of the initial treatments and the absence of early protection from infection. To eliminate any doubt of the ineffectiveness of copper and sulfur sprays and dusts under greenhouse conditions which the above experiment might offer, a further experiment was conducted in the fall of 1925. The treatments were started shortly after the plants were set and continued at weekly intervals. The plants were grown outdoors and set in the greenhouse September 25. The following materials were applied: Bordeaux 3-4-50, copper-lime dust 19-81, New Jersey Dry Mix, sulfur-lime dust 75-25, and Burgundy mixture. A total of eleven applications was made, the first on September 28 and the last on January 6. No control was obtained.

In the fall of 1926 at the Frank Wheeler Estate, Concord, Mass., individual houses were dusted at weekly intervals beginning five days after the plants were set, with Grape Dust, copper-lime dust 20-80, Schloesing's sulfur and Trick sulfur. The dusting was done from between the rows while all the ventilators were closed. Feeney Model-D two-quart dusters with up-turned nozzles were used, and every effort was made to get coverings of dust on the lower leaf surfaces. Five to six pounds of dust were applied each week. The treatments were discontinued after five applications had been made because no control was obtained.

In the fall of 1927 a control experiment was conducted at the Market Garden Field Station in which selected sprays were compared for their effect on the disease. Individual rows were 25 feet long and 3 feet apart. The plants were set July 31. Foliage on both upper and lower sides was as thoroughly wetted with spray as was practically possible. The first treatments were made August 10, and later treatments on August 17, 27, September 2, 9, 19, 28, October 10 and 25, making a total of nine treatments. The vines were topped to the wires on October 25, preceding the last treatment. All of the foliage was covered with fungicide and all of it present at each application was wetted with spray. After August 27 ventilation was purposely neglected to provide favorable conditions for the development of the fungus. The ventilators were closed at night and heat was not used until November 1. Foliage

counts of the prunings were made at intervals during the growth of the crop. The materials used and the tabulated control results are presented in Table 8. As the counts show, none of the materials, except possibly Solbar and Uspulun, was effective. The disease became so serious that no leaves free of Cladosporium were found on the later counts in any of the plats. Solbar and Uspulun furnished the better controls early in the growth of the crop but these were so slight as to have no effect upon the yield or later incidence of the disease. All materials excepting Solbar caused injury; Solbar and lime-sulfur left residues on the fruit; and Uspulun, lime-sulfur and potassium sulfide left an objectionable flavor.

A control experiment with spraying materials was conducted in one of the greenhouses of J. Winthrop Stone in Watertown, Mass. Single rows across the width of the greenhouse were treated with liquid materials selected to offer the best control. The plants were set during the first week in September. Treatments were made on October 7, 17 and 31. There was no leaf-mold present when the first treatments were made. On the first application Uspulun was used at .25 per cent strength and caused burning. In subsequent treatments its strength was reduced to .20 per cent. New Jersey Dry Mix 1.25 per cent was substituted for sulfuric acid .03 per cent in the second treatment on account of injury resulting from the latter. Uspulun, copper sulfate, potassium sulfide, lime-sulfur and New Jersey Dry Mix were injurious to the foliage,—the sulfur materials especially so on the sunny side of the rows. Bordeaux mixture, lime-sulfur, New Jersey Dry Mix and Solbar left heavy residues. Foliage counts were made on November 21, December 14 and January 1 (Table 9). Only treated foliage was considered in the counts, except in the count of January 1 when some of the slightly treated and untreated leaves were included with the prunings. This foliage represented the upper rosette of leaves when the final application of October 31 was made and since the leaves were rather small and sheltered at that time coverings of spray were not as good as on the older and more fully developed leaves represented in the counts previous to January 1. The perceptible residues from Bordeaux, Solbar, lime-sulfur and New Jersey Dry Mix permitted discarding any foliage not showing residue, but since Uspulun, Semesan, potassium sulfide and copper sulfate left no discernible residues no segregation of covered and uncovered leaves was possible. It appears for this reason that the controls of January 1 do not coincide with those previously obtained.

On this crop, heating was practiced liberally from the time the plants were set. Three lines of heating pipe each 12 feet apart extended lengthwise through the greenhouse above the ground in addition to the piping along the side walls. Since it was evident on October 31 when the final treatments were made that liberal heating was controlling the disease effectively, further treatments were discontinued. Infection, therefore, was not severe enough so that the relative efficiency of the materials used could be determined by casual observation. Foliage counts, however, showed a superior effect from Uspulun and Solbar, but the significance of these counts is decreased considerably by the relative lack of disease in the controls.

Spore toxicity studies showed that naphthalene is fungicidal to the spores of Cladosporium and suggest that the frequent disinfection of the tomato vines with naphthalene dust should offer control. This material was considered regardless of the effect its vapors have upon the quality of the fruit. A compartment of the greenhouse with a bed area of 900 square feet and a volume of 10,000 cubic feet was used. The tomatoes were set early in February, 1926. A sulfur-lime-naphthalene dust containing one part of each in-

gredient was used. Nine treatments were made during the interval February 23 to May 13. The disease was observed April 12 and from then on became increasingly prevalent. As early as May it was observed that control was not being obtained and in consequence of that fact treatments were discontinued after May 13. The disease assumed epidemic development, and leaf counts were not considered necessary to demonstrate this fact.

The work has demonstrated that because of the manner of infection of the

Table 8. Control of Tomato Leaf-Mold with Fungicides. Market GardenField Station, Waltham. Fall Crop 1927.

Fungicides	September 1		September 13		October 10		October 31		December 1		Totals	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*
Lime-Sulfur 1%	140	*.7*	202	*4.9*	236	*52.5*	430	*100*	389	*100*	1397	*68.2*
Sulfuric Acid .04%	151	*4.6*	248	*12.0*	203	*98.5*	433	*100*	410	*100*	1445	*74.7*
Uspulun .25%	156	*1.2*	254	*0.3*	302	*23.8*	382	*100*	421	*100*	1515	*57.9*
Copper Sulfate .03%	106	*.0*	120	*0.8*	218	*88.0*	417	*100*	331	*100*	1292	*78.9*
Potassium Sulfide .4%	126	*.0*	131	*9.1*	258	*64.3*	481	*100*	342	*100*	1338	*74.8*
Solbar 1%	265	*1.1*	283	*2.8*	265	*54.3*	392	*100*	370	*100*	1575	*58.2*
Check	310	*9.3*	316	*63.2*	185	*98.8*	401	*100*	400	*100*	1612	*74.6*

Table 9. Control of Tomato Leaf-Mold with Fungicides. Watertown. Fall Crop 1927.

Fungicides	November 21		December 14		January 1		Totals	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*		*per cent*		*per cent*
Bordeaux 4-4-50	454	*7.4*	447	*1.8*	307	*.9*	1208	*3.8*
Semesan .25%	517	*8.4*	372	*2.9*	262	*5.3*	1151	*5.9*
Uspulun .20%	347	*3.4*	452	*.8*	335	*3.8*	1134	*2.5*
Copper Sulfate .04%	509	*6.0*	451	*2.4*	229	*4.8*	1189	*4.4*
Potassium Sulfide .3%	404	*5.1*	324	*6.1*	213	*4.2*	941	*5.3*
Solbar 1%	492	*2.8*	363	*1.3*	223	*1.3*	1078	*2.0*
Lime-Sulfur 1%	351	*5.7*	352	*2.5*	339	*2.9*	1042	*3.7*
New Jersey Dry Mix 1.25%	306	*5.5*	293	*2.4*	209	*9.0*	808	*5.3*
Check	593	*.7*	642	*7.3*	576	*4.1*	1811	*6.4*

foliage and atmospheric conditions under glass, the fungus does not readily lend itself to control with spraying and much less with dusting materials. Spraying is not practicable. A dusting material like naphthalene having an aseptic volatile principle is most promising, but this study has not revealed any materials of such a nature that are effective when applied under commercial conditions of culture. Past recommendations appear to have been based on observational evidence which is misleading. The effect of the fungicide upon the appearance and flavor of the fruit and the health of the foliage, and the practicability of applying fungicidal materials in a manner to promise control were disregarded.

Fumigants

Control of spore germination with naphthalene vapors in Petri dish tests offered encouragement for tests in larger volumes of atmosphere. In a compartment of the greenhouse of a volume of 5,000 cubic feet, 5 pounds of pure naphthalene flakes were vaporized, by the method described by Hartzell (11), from 12 o'clock noon of March 21 to 7 a. m. of the following day. Slides bearing dry spores of Cladosporium were exposed to the treated atmosphere. After fumigation was completed the slides were removed to moist Petri dishes. Normal germination of spores occurred. Naphthalene did not prove effective under the conditions of the experiment. In another trial the same quantity of naphthalene was vaporized and the same method of exposing spores was followed, but the effect was negative. In both tests the maximum quantity of naphthalene per unit volume considered safe to foliage was used. The air temperature during the operation was above 80° F. and the relative humidity close to the saturation point. High temperatures were necessary to prevent condensation of naphthalene on the foliage and injury resulting therefrom. The treatments imparted a strong odor of naphthalene to the tomatoes. For this reason neither the vapors nor the dust are applicable to tomato culture. Parker (28) and Speyer (31, 32) claim that tainting is imparted only to ripe fruit and that the naphthalene flavor leaves the fruit within twenty-four hours after picking, when it is exposed to fresh air. Fruit from tomato houses treated with naphthalene materials was unsalable.

The vapors from a .4 per cent solution of formaldehyde (1-100) are lethal to the spores of Cladosporium (Table 1). A 1-400 mixture is lethal but its vapors are not. Soil disinfection of the greenhouse with formaldehyde 1-100 following which the house was closed tight for 24 hours produced an atmosphere lethal to Cladosporium spores. However, the sterilization of the houses with formaldehyde has not at any time offered any measure of control of the disease on the subsequent crop. The fungus exists in the field and frequently is very prevalent on field tomatoes in Massachusetts. This outside source of the fungus precludes the possibility of obtaining much benefit from soil sterilization and fumigation of the greenhouse with formaldehyde.

Sulfur dusting and spraying materials have not given control. The volatile principle of sulfur (Table 1, V) is not toxic and dusting sulfur in contact with dry spores does not prevent germination. Sulfur dioxide obtained by burning sulfur is lethal and is an excellent fumigant for this purpose. In a single experiment 1¼ pounds of sulfur were burned in a compartment of a volume of 5000 cubic feet, in which were growing tomato vines badly infected with leaf-mold. The time consumed for fumigating was five hours. Slides bearing dry Cladosporium spores were distributed in the greenhouse. After fumigation, reaction tests were made of the foliage, wood, metal and glass surfaces. Acidity was strong even in sheltered portions of leaves covered with

the leaf-mold fungus. Spores on glass slides exposed to the fumigant were killed, and twelve mounts of spores obtained from the treated vines gave no germination. Qualitative tests of the mold on the leaves gave strongly acid reactions. Spores collected previous to fumigation germinated excellently. The fumes of burning sulfur are extremely lethal and penetrating. The practice of burning sulfur before planting tomatoes is an economical and effective means of destroying the fungus and safeguarding the future crop from an inside potential source of attack.

Vaporized Sulfur

Methods of Vaporizing.

Sulfur on heating pipes. The practice of treating the heating pipes with sulfur powders, pastes and liquids prevails among growers of greenhouse plants. It is considered a practical means of controlling certain fungous diseases but has its limitations. In California, because of its mild climate, steam pipe surface in greenhouses is small and very little heat is used, as a result of which the sulfur treatment of the pipes cannot be relied upon to control cucumber powdery mildew, according to Milbrath (25). In Massachusetts, varying results have been obtained in proportion to the area of pipe surface treated and the temperature of the pipes. The value of the practice is very much in dispute among commercial growers. Observations in tomato houses where the practice has been rigidly followed for controlling leaf-mold indicate that it is of doubtful value. According to Parker (27) and Höstermann (14) the sulfur treatment of the heating pipes is not safe at high pipe temperatures. The danger lies in the production of sulfur dioxide, sulfurous and sulfuric acid in sufficient volumes to cause injury to the growing plants. These sulfur oxidation products also have a corrosive action on the pipes, and the scale which forms interferes with the radiation of heat. Pipes treated repeatedly are not considered lasting, and some growers dislike engaging in the practice for that reason. For practical reasons the sulfuring of heating pipes is restricted to the colder months when heat is used. Since the conditions which favor the development of tomato leaf-mold to the extent of causing yield reduction appear usually between the latter part of May and the middle of November, in Massachusetts, when little or no heating is practiced, the use of special heating units for vaporizing sulfur would be extremely economical and desirable.

Mechanical sulfur vaporizers. The vaporization of sulfur with oil stoves has been recommended by Bailey (3), Humphrey (15, 16), Norton and White (26), Maynard (24) and others for controlling powdery mildews. The apparatus suggested was never received with favor by growers of greenhouse plants in spite of the effectiveness of the practice. The oil stoves were not adaptable for operation in large houses, and in small houses where effective results could be realized ignition of the sulfur occurred frequently. The small quantity of sulfur discharged, often giving unsatisfactory control, the danger of its ignition, the necessity of keeping constant watch of the apparatus, and the lack of adaptation of such apparatus to commercial establishments led to its disfavor. More recently Campbell's Patent Sulfur Vaporizer has been used to a limited extent. In the construction of this apparatus provision was made to exclude the oxygen of the air while vaporization is in progress, the purpose being to prevent ignition of the sulfur which, however, it fails to do. Its operation is extremely dangerous to plant life and unpractical for commercial purposes.

Rupprecht (29) and Vogt (34) reported a portable apparatus, the Rota-Generator, so constructed as to prevent the oxidation of sulfur by generating non-oxidized sulfur vapors under the exclusion of air mixed with steam entering under pressure. The sulfur vapors which otherwise would issue slowly are forced out rapidly by steam blasts. The merits claimed for the device are safety of operation, rapid production of vapors, and the extreme fineness of the sulfur. According to Vogt (36) the expectations which some thought were to be realized by this invention have not materialized. It is adapted only to greenhouses, and here its practical value is questionable since interruptions occur in its operation because of mechanical complications in construction.

Improved sulfur vaporizers. The lack of adaptation or acceptance of the patented types of vaporizers led to the study of equipment suitable and practical for use in greenhouses in Massachusetts.

In Massachusetts, electricity is employed for lighting purposes in practically all greenhouse establishments although only the boiler and packing rooms are wired. The writer conceived the idea of vaporizing sulfur in porcelain evaporating dishes on electric hot plates. The flat heating surface of the hot plate was covered with a square of ¼ inch asbestos board with a hole 4½ inches in diameter in which was set a round-bottom porcelain evaporating dish (Plate II A). Two heavy copper insulated wires of No. 6 gauge were installed along the entire length of the greenhouse. At frequent points on the wires electric sockets were connected, into which the hot plates were plugged (Plate II B and C). With a sufficient source of electric current, houses of any capacity may be treated with vaporized sulfur in this manner. Where several large houses comprise the range a power line connected with each house would appear to be most satisfactory. On the other hand, in a range with houses 200 x 30 feet, and with a 25 ampere meter and No. 30 fuses, the lighting circuit should offer sufficient electric current. In any event a strong current is necessary to produce the heat required for vigorous fuming of the sulfur.

The cost of the heating equipment is small. The electric plates retail for $1.00 each, and evaporating dishes 185 mm. in diameter, 50 mm. deep and 765 ml. capacity, for $1.08. The price of ¼ inch asbestos board is $0.20 per pound. The total cost of each unit excluding wires and socket fixtures is about $2.15. When operated on a power line the cost of operation is much less than if on a lighting circuit. The economy and convenience of this method of controlling Cladosporium leaf-mold is appealing.

A sulfur vaporizer designed by the writer and embodying the principle involved in the Rota-Generator but simpler of construction has been used (Plate II D). Water is contained in a cylindrical copper tank, the center of which is provided with a sulfur receptacle of heavy Pyrex glass. Both water and sulfur are heated by an electric hot plate and the steam generated is blasted into the molten sulfur through a metal tube. The sulfur vapors are discharged much more rapidly than with the other apparatus described. The glass sulfur receptacle is undesirable and the metal steam conductor is acted upon by molten sulfur. If these objectionable mechanical features can be overcome this apparatus would prove highly satisfactory for commercial purposes.

Greenhouse Tests.

A series of control experiments were instituted at the Market Garden Field Station greenhouse at Waltham and at the range of Wm. H. Derby, Melrose,

PLATE II

(A) Electric Hot Plate with Asbestos Mat and Evaporating Dish Assembled for Vaporizing Sulfur; (B) Vaporizing Equipment in Operation in Tomato Greenhouse, and (C) in Rose Greenhouse; (D) Sulfur Vaporizer Constructed to Provide Addition of Steam Blasts to Molten Sulfur.

Mass. At Melrose, No. 1 house has a volume of 10,980, No. 2, 37,800, and No. 3, 68,800 cubic feet. At Waltham, No. 7 house has a volume of 10,000, and No. 3, 5,000 cubic feet. Sulfur was vaporized on electric heating units by the method described. The work was done in the evening and all the ventilators were closed for the night to confine the vapors and permit them to settle naturally. The heating units were operated for two to four hours at a time and disconnected when the vapors in the air were quite dense. Counts were made of the leaf prunings to determine the degree of control, and on the last count the plants were stripped of the remaining leaves. This method proved most satisfactory for ascertaining the value of the treatment.

Spring Crop at Melrose, 1926. Sulfur was vaporized 16 times with 5 stoves

at weekly intervals beginning March 2 and ending July 4. The greenhouses were cleaned out July 31. The results of the experiment are shown in Table 10. Both houses in the experiment were subjected to the same conditions.

Table 10.—Control of Tomato Leaf-Mold with Vaporized Sulfur. Melrose. Spring Crop 1926.

Date	Sulfured House No. 2		Check House No. 3	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*
June 2	795	*0.2*	1117	*28.0*
June 29	1207	*0.7*	1540	*55.1*
July 29	2009	*10.8*	1767	*87.4*
Total	**4011**	**5.7**	**4424**	**61.2**

Fall Crop at Melrose, 1926. Three houses of tomatoes were used. The plants were potted July 17 to 20 and treated with vaporized sulfur in the plant house on August 6, using three stoves. The check plants received this single treatment. The houses were set August 20 to 21. Heat was turned on October 1. Seven stoves were used in No. 3 house and six in No. 2 house. Sulfur was vaporized nine times in No. 3 house, the first on August 31 and the last on October 18; and eight times in No. 2 house, the first on September 1 and the last on October 19. The houses were cleaned out January 30 to 31. The results are presented in Table 11.

Table 11.—Control of Tomato Leaf-Mold with Vaporized Sulfur. Melrose. Fall Crop 1926.

Date	Check House No. 1		Sulfured House No. 2		Sulfured House No. 3	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*		*per cent*
November 1	692	*13.8*	985	*3.9*	1256	*3.4*
December 8	1339	*49.2*	893	*8.5*	1467	*3.6*
December 27	833	*57.6*	1441	*10.6*	1609	*5.1*
January 25	730	*59.3*	1088	*17.4*	734	*14.9*
Total	**3594**	**46.3**	**4407**	**10.4**	**5066**	**5.7**

Fall Crop at Waltham, 1926. Two compartments of the greenhouse were used. The plants were set August 19 to 20, fifteen inches apart in single rows 30 inches apart. Eight times at weekly intervals from August 23 to October 11 sulfur was vaporized with one stove for periods varying from 60 to 90 minutes (connection to disconnection of electricity). The compartments were cleaned out February 1, 1927 (Table 12).

Table 12. Control of Tomato Leaf-Mold with Vaporized Sulfur. Waltham. Fall Crop 1926.

Date	Sulfured House No. 3		Check House No. 7	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*
September 20	529	*5.2*	396	*9.5*
October 1	585	*1.5*	1368	*2.4*
October 10	553	*0.7*	2259	*23.1*
December 20	428	*17.5*	1096	*75.1*
January 11	1130	*4.6*	1433	*56.3*
January 29	1027	*5.7*	1081	*27.1*
Total	**4252**	**5.3**	**7633**	**33.0**

Spring Crop at Melrose 1927. Three houses were employed in the experiment, two of which were treated with vaporized sulfur (Table 13). The houses were set in the middle of February. Six stoves were used in No. 2 house and eight in No. 3 house. The stoves were operated sixteen times in No. 2 house beginning March 2 and ending June 24; and fifteen times in No. 3 house beginning March 7 and ending June 30. At these intervals electricity was used for periods of one to two and one-half hours, a total of 24½ hours for No. 2 house and 26¾ hours for No. 3 house for the season. All three houses were grown under the same conditions. The houses were cleaned out the last week of July.

Table 13. Control of Tomato Leaf-Mold with Vaporized Sulfur. Melrose. Spring Crop 1927.

Date	Check House No. 1		Sulfured House No. 2		Sulfured House No. 3	
	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased	Leaflets Counted	Leaflets Diseased
		per cent		*per cent*		*per cent*
June 16	985	*6.09*	1227	*.08*	1174	*.08*
July 6	481	*41.99*	540	*.00*	701	*.14*
July 19	816	*98.52*	726	*.00*	1146	*.00*
Total	**2282**	**46.71**	**2493**	**.04**	**3021**	**.06**

Fall Crop at Melrose 1927. Four houses were treated with vaporized sulfur and one house was left untreated. No leaf counts were made, but frequent observations during the growth of the vines showed that vaporized sulfur furnished almost perfect control of infection. Leaf-mold was hard to find. In the untreated greenhouse the disease was epidemic and as a result the yield was poor and of second grade.

Recommendations

The conditions predisposing to epidemics of leaf-mold occur between May and November in Massachusetts, which obviates the necessity of particular recommendations for each crop. The spring crop is less affected than the fall crop. This crop should run from February to July, inclusive, and since most of the damage occurs late in June and in July the loss is usually small. The spring crop is started in the cold season of the year when continuous heating is required and does not encounter conditions favorable for the development of leaf-mold until the sun's rays become stronger and heating is discontinued. The fall crop is started early in August. During the first two months the sun's rays are intense, the nights are damp, and no heat is used. The plants are exposed to the danger of epidemic infection up to the time winter weather appears, or usually until about the middle of November, when continuous heating is required. For this reason the fall crop suffers heavily from leaf-mold, often to the extent of shortening the picking season by 1½ to 2 months. Consequently, sulfur should be vaporized in the plant house to guard against infection of the young potted plants.

Immediately following the setting of the houses a further treatment should be made and then repeated at weekly intervals as long as steady heating is not necessary. The foliage infection counts on the spring crops, and observations on the first appearance of the disease suggest that treatments previous to April are not necessary in Massachusetts. The steady use of heat at night and the mild house temperatures during the day up to this time may be relied upon to keep the disease under control.

The simple operation of vaporizing sulfur by the method advocated in this paper offers a practical and efficient means of combating fungous diseases in greenhouses. The striking control of Cladosporium leaf-mold, otherwise only possible by consistent management of air conditions and the liberal use of heat, suggest remarkable possibilities of the adaptation of this method to the control of other fungous parasites of greenhouse plants.

SUMMARY

Sulfur suspensions in water and dusting materials are not fungicidal to germinating spores of *Cladosporium fulvum*. Lime-sulfur and potassium sulfide at high concentrations and temperatures show some merit. Copper fungicides are toxic in the presence of moisture. Lime is not fungicidal. Schacht's Naphtal-Schwefel, naphthalene preparations, Uspulun and Semesan are fungicidal. Formaldehyde, the oxidation products of burning sulfur, and naphthalene are toxic fumigants. Hammond's Slug Shot and Hammond's Grape Dust, each containing a small percentage of copper sulfate, have a slight fungicidal effect in the water drop. Sulfuric acid is toxic at extremely low concentrations by all methods of study, and copper sulfate similarly at stronger concentrations. Vaporized sulfur is toxic, but greatest effect is shown in the presence of moisture.

Control of infection of potted plants inoculated with spores in water was best with copper fungicides, organic mercury, and vaporized sulfur. Lime-sulfur and Hammond's Slug Shot, tested but once, gave favorable control. When the plants were dusted with spores, only vaporized sulfur gave consistent control, while Solbar in a single test gave favorable control.

Only vaporized sulfur has given control of the disease under commercial conditions of tomato culture. Uspulun and Solbar sprays showed some fungicidal value.

The use of spraying or dusting materials under greenhouse conditions is not practical or effective because of (1) The objectionable flavor imparted to fruit, (2) Objectionable residue on fruit, (3) Toxicity to the foliage, (4) Difficulty of covering surfaces which become infected, (5) Lack of conditions necessary to obtain toxicity, and (6) The need of frequent treatments to maintain protection and disinfection.

The expense of firing for the purpose of vaporizing sulfur on the steam pipes on the fall tomato crop is prohibitive. During the heating season the vaporization of sulfur on the pipes may be practiced, but the value of this method for controlling leaf-mold is doubtful. In the absence of pipe heat conditions prevail which favor epidemics of leaf-mold. Electrical equipment for vaporizing sulfur on a commercial scale provides a very economical, practical and effective method of controlling tomato leaf-mold in the greenhouse. The practice offers possibilities of dealing effectively with foliage diseases of greenhouse plants, and is considered a great improvement over existing methods of dusting and spraying.

LITERATURE CITED

1. Anonymous. De Bladvlekkenziekte der Tomaten. Floralia 48:363-364, 1927.
2. Baehr, ——. Die Tomatenfleckenkrankheit, *Cladosporium fulvum*. Möllers Deut. Gärt. Ztg. 38:204, 1923.
3. Bailey, L. H. The forcing of English cucumbers. N. Y. (Cornell) Agr. Expt. Sta. Bul. 31:123-139, 1891.
4. Barker, B. T. P., Gimingham, C. T. and Wiltshire, S. P. Sulfur as a fungicide. Univ. Bristol, Agr. and Hort. Research Sta. Ann. Rpt. (1919):57-75, 1920.
5. ————, and Wallace, T. A new method of sulfur fumigation. Univ. Bristol, Agr. and Hort. Research Sta. Ann. Rpt. (1921):122-124, 1922.
6. Bewley, W. F. Diseases of glasshouse plants. 208 p. London, 1923.
7. D., A. M. Flojlsplet. Gartner-Tidende 43:41-45, 1927.
8. Dyke, W. The A. B. C. of tomato culture under glass. 165 p. London, 1925.
9. Edgerton, G. W. Delayed ripening of tomatoes caused by spraying with Bordeaux mixture. Phytopathology 8:69, 1918. (Abstract.)
10. ———— and Moreland, C. C. Diseases of tomatoes in Louisiana. La. Agr. Expt. Sta. Bul. 142, 23 p., 1913.
11. Hartzell, A. Naphthalene fumigation of greenhouses. Jour. Econ. Ent. 19:13-19, 1926. Reprinted as Boyce Thompson Inst. for Plant Research Prof. Paper 3:13-19, 1926.
12. Hasper, E. Biologie und Bekampfung des *Cladosporium fulvum* Cke. auf *Solanum lycopersicum*. Ztschr. Pflanzenkrank. 35:112-118, 1925.
13. Hofferichter, K. Eine verheerende Tomatenkrankheit. Gartenflora 73: 60-61, 1924.
14. Höstermann, G. Eine bedenklicke Art der Verwendung von Schwefel als Pflanzenschutzmittel. Gartenwelt 28:183-184, 1924.
15. Humphrey, J. E. The powdery mildew of the cucumber,—*Erysiphe cichoracearum* DC. Mass. State Agr. Expt. Sta. Ann. Rpt. (1891) 9:222-226, 1892.
16. ———— Treatment for powdery mildews. Mass. State. Agr. Expt. Sta. Ann. Rpt. (1892) 10:243-245, 1893.

17. Jaenicke, A. Einiges über Tomatenkrankheiten unter Glas im Jahre 1927. Obst. und Gemüsebau 73:261-263, 1927.
18. Jonassen, E. Tomatenkrankheit, *Cladosporium fulvum.* Möllers Deut. Gärt. Ztg. 38:276, 1923.
19. Kraemer, H. Dilute sulfuric acid as a fungicide. Amer. Phil. Soc. Proc. 45:157-163, 1906.
20. ———— Use of dilute solutions of sulfuric acid as a fungicide. Science n. ser. 23:941, 1906.
21. Lüstner, G. Der Tomatenkrebs. Obst. und Gemüsebau 73:166-167, 1927.
22. Makemson, W. K. The leaf mold of tomatoes caused by *Cladosporium fulvum* Cke. Mich. Acad. Sci. Ann. Rpt. (1918) 20:311-348, 1919.
23. Massey, W. F. and Rhodes, A. Gardening under glass. N. C. Agr. Expt. Sta. Bul. 170, 24 p., 1900.
24. Maynard, S. T. Experiments in heating greenhouses. Mass. (Hatch) Agr. Expt. Sta. Bul. 4:1-22, 1889.
25. Milbrath, D. G. Control of diseases of cucumbers in greenhouses. Calif. Dept. Agr. Mo. Bul. 11:430-437, 1922.
26. Norton, J. B. S. and White, T. H. Rose mildew. Md. Agr. Expt. Sta. Bul. 156:73-80, 1911.
27. Parker, T. The suppression of insect pests and fungoid diseases. 4. Control of certain fungoid diseases. Bur. Bio-Technol., Leeds, Bul. 2: No. 10:68-72, 1923.
28. ———— The control of red spider. Hort. Trade Jour. 29: No. 39: 27-28, 1925; No. 40:27-28, 1925.
29. Rupprecht, G. Ein neues Verfahren zum Schwefeln von Pflanzenkulturen. Angew. Bot. 3:253-262, 1921.
30. Sherbakoff, C. D. Tomato diseases. Fla. Agr. Expt. Sta. Bul. 146:117-132, 1918.
31. Speyer, E. R. The use of naphthalene as a fumigant in control of red spider and other pests in cucumber houses. Nature [London] 114: No. 2858:193, 1924.
32. ———— Entomological investigations. Expt. and Research Sta., Cheshunt, Herts, Ann. Rpt. (1924) 10:82-104, 1925.
33. Triebels, H. Die Bekampfung der Braunfleckenkrankheit bei Tomaten. Gartenwelt 31:368-370, 1927.
34. Vogt, E. Ein neuer Schwefelapparat. Nachrichtenbl. f. d. deut. Pflanzenschutzdienst 1:4:29, 1921.
35. ———— Untersuchungen über den Schwefel. Angew. Bot. 6:276-300, 1924.
36. ———— Die chemischen Pflanzenschutzmittel, ihre Anwendung und Wirkung. 134 p. Berlin, 1926.
37. Weber, G. F. and Ramsey, G. B. Tomato diseases in Florida. Fla. Agr. Expt. Sta. Bul. 185:61-138, 1926.
38. Williams, P. H. Tomato leaf-mold. Expt. and Research Sta., Cheshunt, Herts, Ann. Rpt. (1925) 11:67-72, 1926.

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